A STUDIO MANUAL FOR CASTING BRONZE BY THE LOST-WAX METHOD.

Presented to

The Art Faculty
of
University of Minnesota, Duluth

by
Terry M. Anderson
for the degree of

Master of Arts

August 1974
Duluth, Minnesota

" TOPOGRAPHIC II "

24 x 18 inch bronze relief

This bronze casting done by myself, portrays my fascination and delight towards the method of lost-wax casting. It also contains my interest in geology, aerial photography, and cartography. Earth, air, and fire generate the creation of the bronze through the technic; just as the earth, and its own evolution through a a similar technic, is the subject matter. For myself, the execution of the bronze is similar to the geological manifestations of tectonics itself; hopefully, giving to the viewer and myself a glimpse of the magnetude, soundness, and sensuous reality of the earth.

- CONTENTS -

Development of Casting 1

Introduction to the Method 3

What is the Value of the Process? 8

The Materials 10

- Bronze 10
- Wax 11
- Plaster 12

The Plaster Mold 13

The Wax Pattern 20

- Melting the Wax. 20
- Making the Pattern 20

The Sprue System 22

- Sprueing the Wax Pattern 22
- Making the Sprues & Runners. 27
- Examples of Sprue Systems. 28

Investment 31

- Types of Investment 31
- Investing the Wax 33

Burnout 42

Packing the Molds 43

Melting & Pouring 45

- Care & Use of the Crucible 45
- Charging the Crucible With Bronze. 45
- Preheating the Charge Bronze 46
- The Crucible Rest 46
- The Crucible Tongs & Shank 46
- Melting the Bronze 47
- Illustrations of the Pour 48

Patination 57

- Patina Application 58
- 21 Patina Formula. 60

Summary 63

Footnotes 64

Bibliography. 65

THE DEVELOPMENT OF BRONZE CASTING

The technic employed in casting bronze has little changed since Biblical times, when Aaron cast his golden calf. Albeit the story of Aaron could be myth, sufficient evidence remains to prove that bronze was cast in very early historical times. Bronze bells and other castings have been found in China, their marks indicating that they were cast circa 2000 B.C.[1] Earlier castings have been found in India, these dating from 5000 B.C.[2] Seemingly many major civilizations have evolved a technic for bronze casting.

Before the casting technic was developed, bronze was hammered into thin sheets, then beaten to conform to wooden or bituminous molds. The metal surface could be tooled in great detail. This technic, although producing fine results, had its drawbacks. The form had to be annealed and hammered many times, and total freedom of form was limited. The casting of metal made possible larger, more substantial forms which could now be as fluid in concept and design as the wax model would permit. The originator of the lost wax process remains anonymous. Most likely, early bronze forms were exclusively weapons or tools. Most of the technical advancements in early metallurgy indicate the pursuit of a better weapon.

Most of the fine bronze articles of the past are lost. Invaders could destroy the forms by building a fire inside or out. Many other valuable pieces were loaded on camel or ship, destined for one of the great Mediterranean cities. Eventually, the prized bronzes reached the sovereign city-Rome. This historical analysis well accounts for the prominent role of the Italians have taken in bronze casting. Large quantities of bronze scrap encouraged artists to perpetuate their ideas in that medium. Thus, since the Bronze Age, man through all of his civilizations has produced bronze articles. Because so many bronzes have been preserved, today's museums serve as virtual warehouses for them.

The process of lost wax casting was perpetuated and protected by various craft guilds. Until recent times, sculptors knew nothing of the technic. Before the knowledge of bronze casting was disseminated, the artist would take his model to a foundry where it would be cast for him. The artist remained uninformed as to the bronze casting method. The artist of today finds advantage in learning the methods of bronze casting-not only is it to his financial advantage; but he prefers to work out his aesthetic feelings for technic himself. The once guarded secrets of casting are now promulgated by artists, students and institutions of higher learning.

AN INTRODUCTION TO THE METHOD

Before moving into the particular methods and problems of lost-wax casting, a summerization of procedure is necessary. The form to be cast is made of wax or a similar material that will burn out and leave little residue. (Fig. 1) Here a head study has been made in wax; the thickness of the wax is about 3/16".

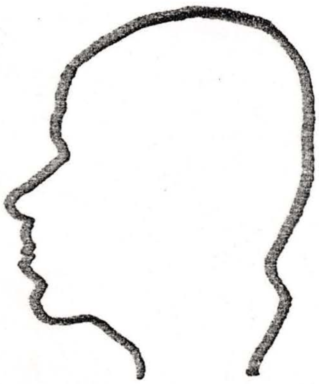


Fig. 1 - The Wax Pattern

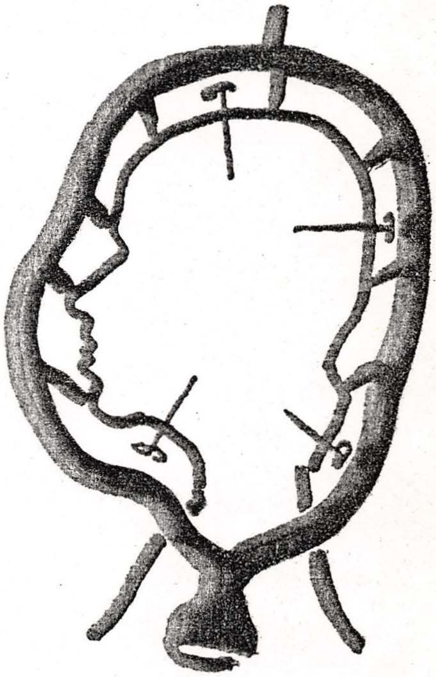


Fig. 2 - The Sprue System and Core Pins

(Fig. 2) The sprue system is attached to the wax pattern. Sprues and vents in the shape of wax rods are attached to designated points on the wax form and arranged in a manner to distribute the molten bronze rapidly and uniformly to all parts of the mold with a minimum of turbulence. These wax rods range in size and form from 1/4" to 1" in diameter, varying according to the size of the casting and the amount of metal to be distributed. Because of the weight and shrinkage of bronze, most castings are made hollow - the wax form or pattern is also hollow. The thickness of the wax and consequently, the bronze, is about 1/8" - 3/16".

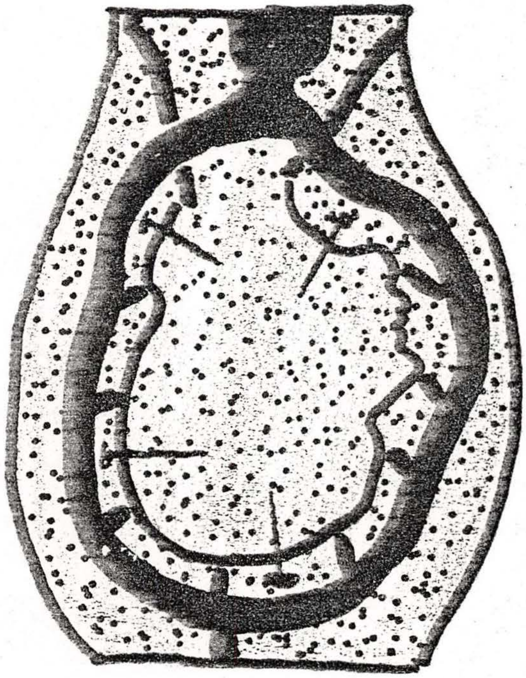


Fig. 3 - The Investment

(Fig. 3) The wax pattern with the sprue system attached is now enclosed in a plastic refractory material-investment. Because the bronze will be hollow, the investment must also be on the inside of the wax pattern. This core must be anchored substantially in order to retain its proper position with relation to the outside of the mold at two critical periods - after the wax support has been melted away and while the molten bronze is exerting heavy pressure in filling the space between the inner core and the exterior mold. The anchoring is achieved by core pins, or nails penetrating through the wax and linking the mold and core once the wax is melted away. (See Fig. 2)

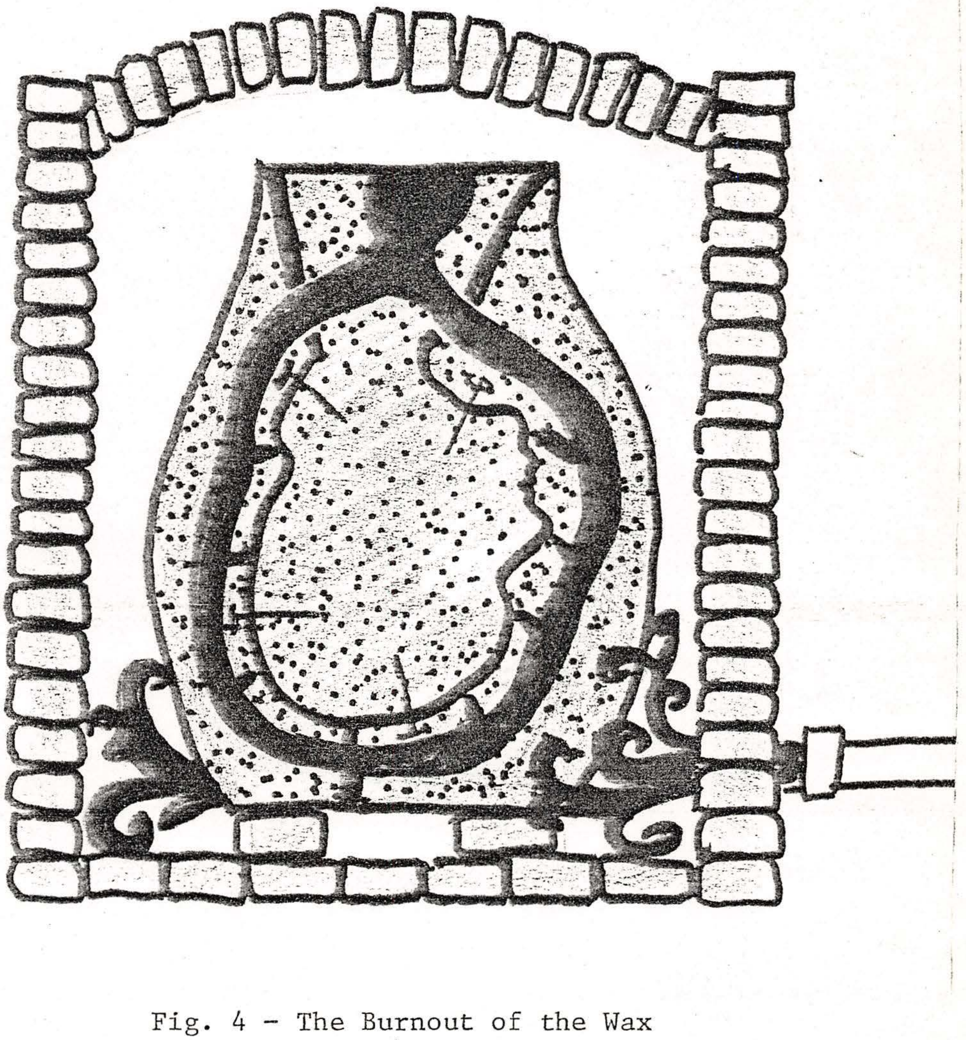


Fig. 4 - The Burnout of the Wax

The entire assemblage is allowed to set up (the investment being partially plaster) and is placed in a kiln or oven. (Fig. 4) The kiln <u>should</u> surround the mold with a minimum of wasted space. The mold is then fired to a temperature of around 1000 degrees F., or until the wax and moisture are completely driven out. Firing time may range from one to two days, depending on the sizes of and number of molds.

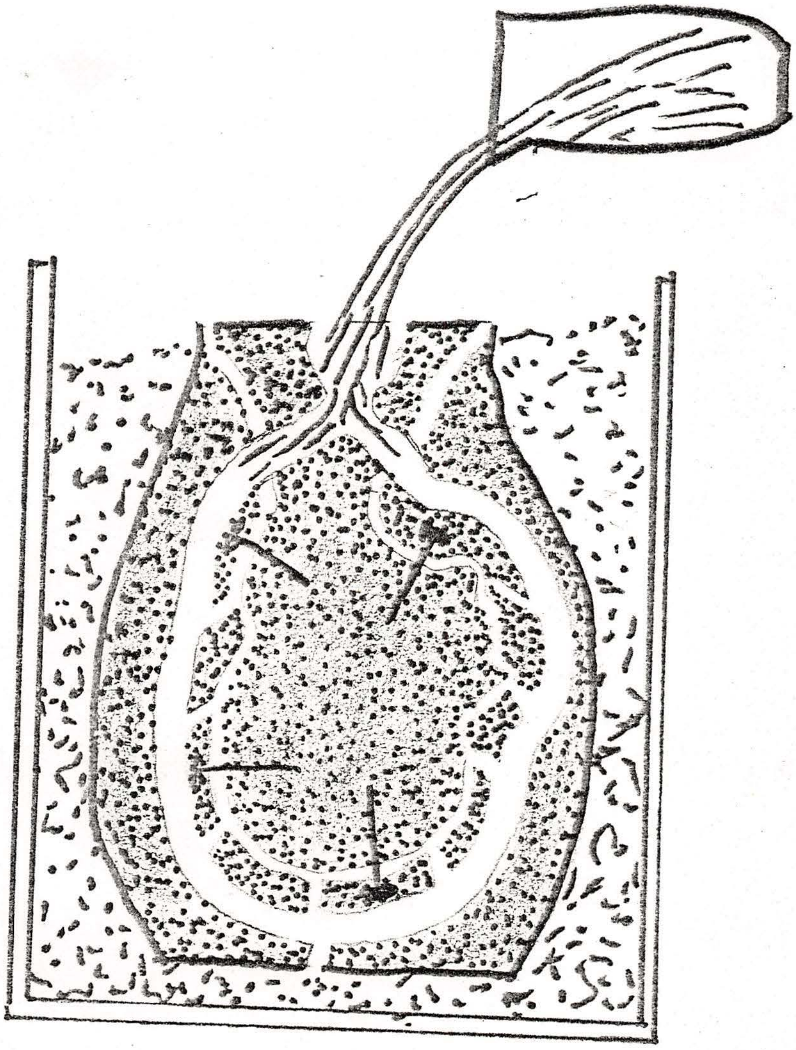


Fig. 5 - Packing the Mold and Pouring the Bronze

(Fig. 5) After being allowed to cool in the kiln, the mold is carefully placed in a pit or a large container of sand. Being slightly damp and cohesive, the sand is tightly rammed into the space between the molds and the container walls. The packed sand assists the mold when it is being filled with molten bronze by helping resist the pressure and weight exerted from the inflow of the metal being poured. After proper cooling the casting is removed from the sand and investment mold and cleaned. Sprues, core pins and core are removed; any holes are repaired and the surface is tooled to a final finish. A patina (surface color) can then be applied. Patinas can give a variety of color effects. The bronze surface is treated to produce the various copper and iron compounds. Patinas are not applied or superficial colors, but rather an actual modification of the surface and an integral part of the bronze.

Keeping in mind the overview of the bronze casting process, one can now consider the variables, which can be manipulated, often to one's success or failure. This paper will narrow the range of variables to a more tolerable lend.

WHAT IS THE VALUE OF THE LOST-WAX PROCESS?

Bronze casting deals with much more than technical considerations. Aesthetic implications of the method should also be looked into.

> "I think technic is similar to vocabulary in terms of talking and thinking. I don't think we can conceive verbally, I mean, without words to conceive with. I don't believe we can create visually without the technical means already absorbed, pre-absorbed or pre-programmed, ...
> In other words, if we know that metal has certain characteristics such as flowing, we can "think" then, or we can conceive then, in terms of form, which result from this." [3]

Many arguments against the lost-wax casting process have been raised - the method is absurdly indirect, it lacks integrity for material, bronze as a contemporary material is dead, bronze is expensive, the technic is tedious, etc. In most peoples minds, these are the drawbacks to the lost-wax process. But, perhaps they are "overlooking" the method and missing some of its inherent ideas.

Perhaps in the idea of "transition" lies the worth of the lost-wax process the transition of ideas through material changes. For example, one can begin by modeling an image in clay, a fluid, plastic material which will take form very easily. From the clay image a plaster mold is made. This process need not be tedious, but rather a <u>whole</u> dimension of positive and negative imagery may arise. The original clay image of the modeled form can remain whole and continuous by means of a complete mold. Parts of the original form can be contrasted or joined (as male and female) by using only disjoined parts of the mold. A rhythm of vibrant forms and images can be set up by the manipulation of parts of the mold, inherent in the process of the mold is the essence of birth, of fetus and of womb and death. A mold can be the continuation of a sculptural idea.

Following the concept of transition, a wax pattern is taken from the mold. This wax will become the exact form of the original clay. In other instances, the wax can be treated directly. It can be flashed with a flame, carved, bent or modeled. The wax pattern is then encased in a shell of fire resistant material (investment) where it is melted out (hence lost-wax process) leaving an empty cavity. The original image gone, only the fragile shell remains after firing. The cavity is only made whole again when the bronze is poured in.

There is a certain character to the process of lost wax. One can experience a richness in the qualities of plastic clay and moldable wax, the negative mold, the fire of casting and the array of colors and textures that can be achieved in the final bronze.

Hopefully, those who proceed to cast will enjoy the process equally with the outcome, for in the process lie inherent ideas, new directions, and a philosophy that can give soundness to the finished form.

THE MATERIALS

Bronze

There are numerous metals that can be cast. Traditionally and for reasons of strength, color, castability and resistance to corrosion, bronze has been the preferred metal. Essentially bronze is an alloy of copper and tin. Small proportions of other metals are sometimes added for reasons of physical strength corrosion resistance or appearance. One of the ancient bronze alloys consisted of 88 parts copper, 10 parts tin and 2 parts zinc.[4] The addition of tin and zinc give the copper a greater tensile strength. The standard bronze compositions of today are similar in make-up.

Aluminum can be alloyed with copper. Lead can be added to lower the melting temperature. Silver can be added to change the color. Each of the many alloys of bronze is distinct. The melting temperature may vary greatly. Some need fluxes when melted and most cannot be mixed one with the other. It is very important that the composition of the alloy and its properties be understood before casting. Bronze should not be contaminated with any other metal, nor any other alloy of bronze, unless compatibility has been established. The composition of scrap bronze should be ascertained before use. It should be clean. In most cases, it is best to purchase new ingots, which cost little more than scrap. They are guaranteed as to their composition. If problems arise in the casting one can eliminate the metal as the source of the problem.

One alloy that should be stressed for foundary use is silicon bronze. It is very fluid when melted and will readily cast into thin, complex sections. This metal does not form a heavy slag, nor does it need a flux when melted. One thing that affects the castability of bronzes is the presence of oxides.

Tin (found in most alloys) readily forms tin oxide when melted. This oxide forms quickly and will impede the fluidity of the metal. Silicon forms no stable oxide when melted and silicon bronze is a relatively clean metal when poured.[5] The composition of silicon bronze is essentially copper and 4% silicon. There may be small amounts of zinc or maganese and other trace elements.

Wax

Much time spent in lost wax casting is in the production of a suitably finished wax pattern. There are two means of getting a wax pattern. It can be made by molding the wax directly (direct wax casting) or by taking a wax pattern from a mold (indirect wax casting).

Making a direct wax sculpture of any size is difficult because the inside of the wax must be a predetirmined core. The core is made of a refractory material to within what will be the end thickness of the bronze. Wax is spread over the core to achieve this final thickness. Final modeling is done on the wax. My emphasis will be given to the indirect method, since many sculptures are not first conceived in wax, but rather in clay, wood, plaster or other materials. From these materials a plaster mold is made and a wax pattern is taken.

Two types of wax are derived from petroleum - Paraffin and microcrystalline. Microcrystalline is best suited for studio use. Paraffin is brittle and cracks when bent. Microcrystalline waxes bend easily and are not brittle. There are many varities of microcrystalline wax, with melting temperatures ranging from 140 degrees F. to 200 degrees F. They can be softened by being mixed with vasaline or petroleum jelly.

Much care should be exercised when working with any kind of wax. If wax is overheated it may ignite and cause severe burns. Microcrystalline wax does not ignite until it reaches about 500 degrees F. As it melts at a much lower temperature, it gives allowance for a good safety margin.

Plaster

The use of gypsum or plaster as a sculptural material goes back 4500 years. Casts from faces and other parts of the body have been found in Egypt and date from 2400 B.C.[6] From the Egyptians through the Greeks and to the present day, plaster ranks as one of the most versatile materials of the sculptor. One should try to understand some of its physical and chemical properties. Plaster is $CaSO_4$ one-half H_2O or sulphate of calcium. It is made from $CaSO_4 - 2H_2O$ or hydrated calcium sulphate.[7] From looking at the two equations, one can see that plaster is dehydrated gypsum. The sculptor just re-adds the water - a bit of magic.

Plaster should always be added to water. Sprinkle dry plaster uniformly over the surface of the water. Never drop in whole handfuls, as the result will be a lumpy, hard to blend mixture. Keep adding until the water is completely saturated with plaster. Let stand until bubbling and saturation are complete. Properly mixed, plaster will set up in 20 minutes. Mixing should be done from the bottom as this will keep air bubbles from being trapped in the mix. Excessive mixing should be avoided as it causes the plaster to set too quickly. If the plaster is mixed during its setting phase, it will not harden. Vigorous mixing using hot water, or using a rich mixture of plaster to water causes the plaster to set quickly. Minimal, gentle mixing, cold water and the use of less plaster will retard the setting time.

THE PLASTER MOLD

Molds are made for several reasons - to transfer the form into wax, to make duplicate copies or as an integral part of the finished concept. Traditionally, mold making has been an important part of the sculptor's repretoire. Today the tendency is to seperate technic from the creative process. This development only hinders the sculptor, limiting his freedom of expression , narrowing his direction and confining his imagination for lack of knowledge.

The form to be cast in a plaster mold should be studied to find the simplest and most apparent divisions. This will indicate how to make the mold easy to remove and reassemble to pour the wax pattern.

Plate 1

The figure (1) is made of solid wax, about 7 inches high. A mold is being made from it so the figure can be made hollow and in duplicate. A clay wall surrounds the figure where there are no undercuts. This assures that first piece of the plaster mold will release easily. The clay shim is a uniform ½" wide.

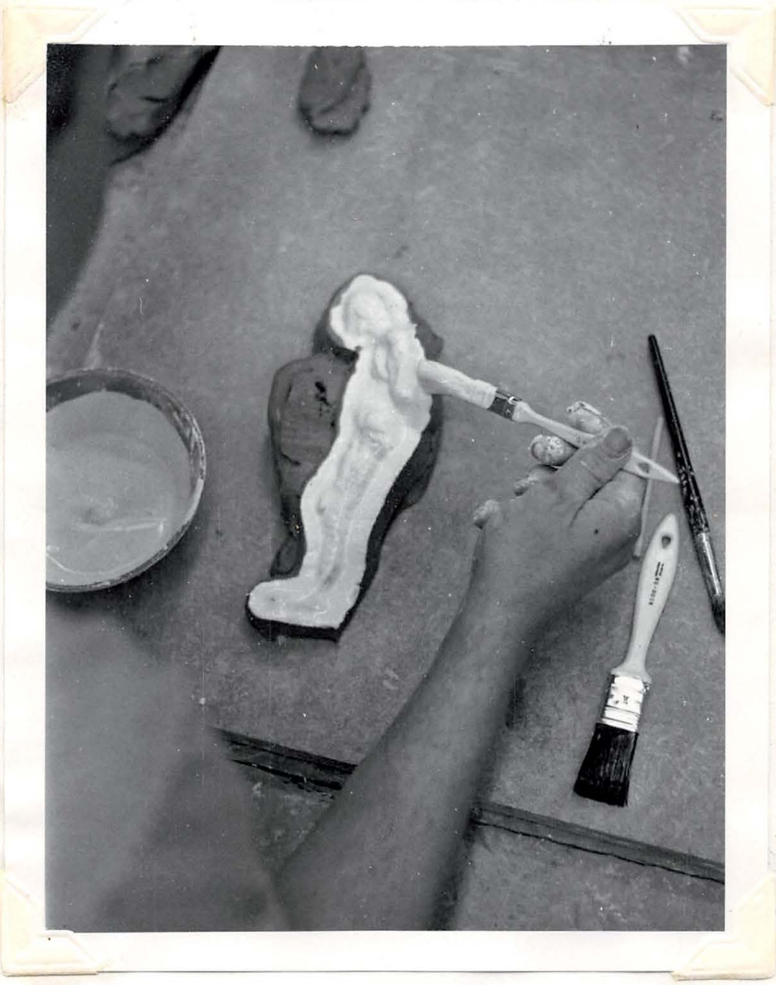


Plate 2

(2) About one cup of plaster is mixed. The first coat, carefully painted on, prevents air entrapment.

(3) A number "9" tool is used to apply the plaster as it begins to set.

Plate 3

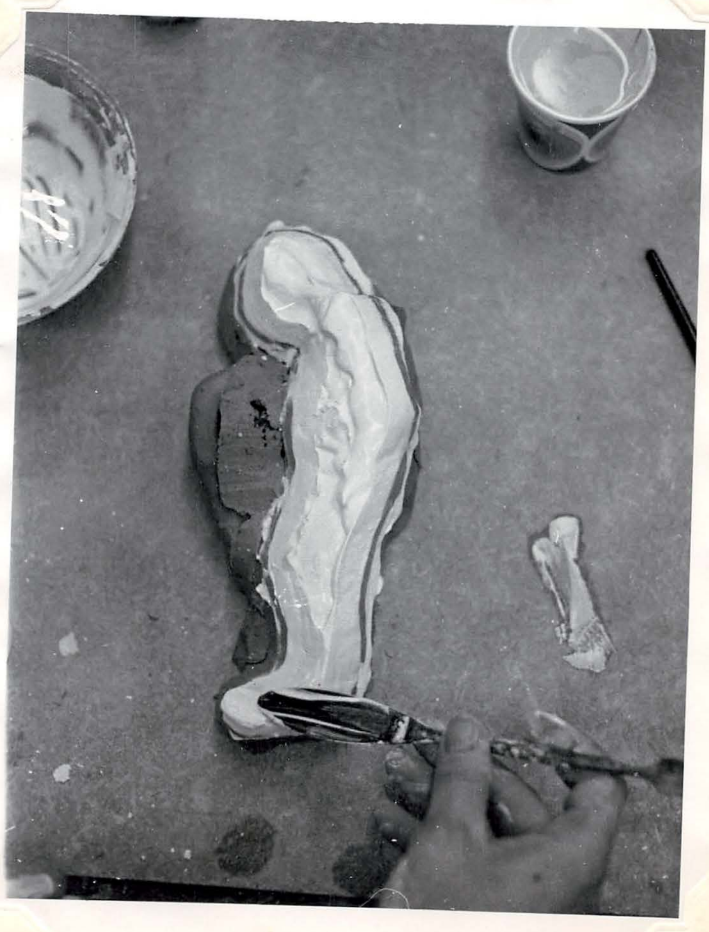


Plate 4

(4) The same tool smooths the surface as the plaster reaches a "frosting-like" consistency.

(5) The first piece has hardened in about 20 minutes. The clay has been removed and the next piece will be made. Notice the undercut in between the two arms. It prevents the whole back from being made in one piece.

Plate 5

(6) A piece has been made in this portion of the back. Two keys have been carved to prevent the piece from shifting when it is connected to the back piece. A separator must be used to keep the pieces from sticking together. A non detergent soap solution works well - Fels Naptha or Ivory Snow. Green soap or clay slip works well also. The separator is brushed over the plaster. After it soaks in for a few seconds, any excess is brushed away to prevent its going into solution with the plaster where it is applied.

Soap mixed with plaster prevents plaster hardening.

Plate 6

(7 & 8) After the two pieces have been soaped, the third piece is applied over the back. The whole process continues until the mold is complete.

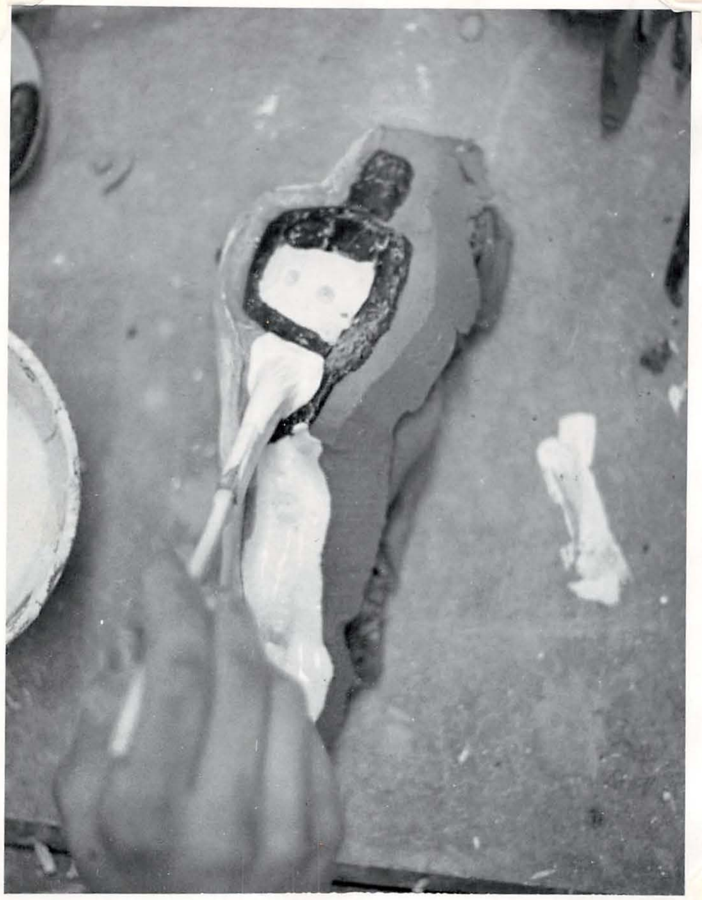


Plate 7

Plate 8

Plate 9

(9) When the plaster is set, the pieces can be removed. There will be some resistance. Pouring hot water into the seams softens and relieves the resistance of the wax. Clean the pieces out with a soft brush. Any concave errors in the mold can be filled with soft clay. For wax pouring, a ½" hole is carved in one of the top mold pieces. The hole can later be repaired with wax. A wax pattern can now be taken from the mold.

THE WAX PATTERN

Melting the Wax

If the wax is solid in the pan,melt a small area of wax on the edge of the pan before putting it directly over the burner. This will relieve the tension of the expanding, melting wax at the bottom of the pan and allow its coming to the surface instead of exploding. Rapid melting and high heat are not necessary. Wax does not conduct heat well. If the melted wax starts to make a boiling sound, water is present in the wax. This can be very dangerous since it causes the wax to bubble and spatter. The noise also indicates a temperature which is, in most cases, too hot. Another indicato of excess temperature in microcrystalline wax is odor. At working temperatures (between 200° - 275°) the wax is almost odorless. At excess temperatures it gives off oily fumes.

Making the Pattern

There are 3 methods for making a wax pattern, pouring, painting and a combination of both. In all cases the plaster mold must be wet or the hot wax will stick to the plaster surface. After the mold has soaked in water, remove it and sponge off any excess surface water. Bind the mold pieces together with clamps, rubber bands or rope. If the seams between the mold pieces are not snug, clay can be pushed into the seam. Pour the mold full of hot wax, then immediately pour the wax back out. A wax layer of 1/16" will have built up on the surface. If the wax from this first pour had been left in the mold too long it would have heated up certain thin or delicate areas of the plaster mold. The deposition of wax in these areas would then become thinner and thinner. The wax temperature in this first pour is fairly hot, so as not to make chill or ripple marks on the mold surface from rapid cooling. Now let the pan of hot wax cool off, so that when it is poured in the mold ,it does not remelt the first wax coat. Pour this cooler wax back into the mold. Slowly rotate the mold as the wax is poured back out to get a uniform wax coating on the mold. When pouring the wax back out make sure it does not gurgle, as this slight vacuum may cause the warm wax inside the mold to collapse on distort. Sometimes in a complex mold an air vent with a removable plug is used to facilitate filling and emptying the mold of wax. The process is repeated until the desired thickness is achieved. Remember that the thickness of the wax will be the thickness of the bronze. The mold is then placed in cold water to cool, the pieces are carefully pulled off the wax pattern.

Good results can also be achieved by brushing the wax into the mold. The best brush to use is a natural bristle brush. A nylon brush would melt.

The essential idea in brushing is to apply the brushful of wax quickly before it freezes. Never keep brushing after the wax starts to thicken. S tart slapping the brushfuls of hot wax on the mold from the bottom up. This helps avoid lapping lines. If the brush can not be gotten into the mold, the individual pieces of the mold can be separately painted with a thin layer of wax. The edges are then trimmed of the pieces put together, and hot wax poured in as in the first method.

When the mold is taken off the wax can be given its final repairs or retouchings. Johnson's paste wax works well for filling bubbles, pits or undesirable cavities on the surface of the wax. The wax pattern is now ready for sprueing.

THE SPRUE SYSTEM

Sprueing the Wax Pattern

The sprue system is to the wax pattern as the veins and arteries are to the human body. This system provides the channels for the wax to run out of the mold and for the introduction of the molten metal during casting. (Fig. 6) Following is an example of a sprue system for a head to be cast in bronze. To better understand the casting process, one should become, acquainted with the terms and the function of each.

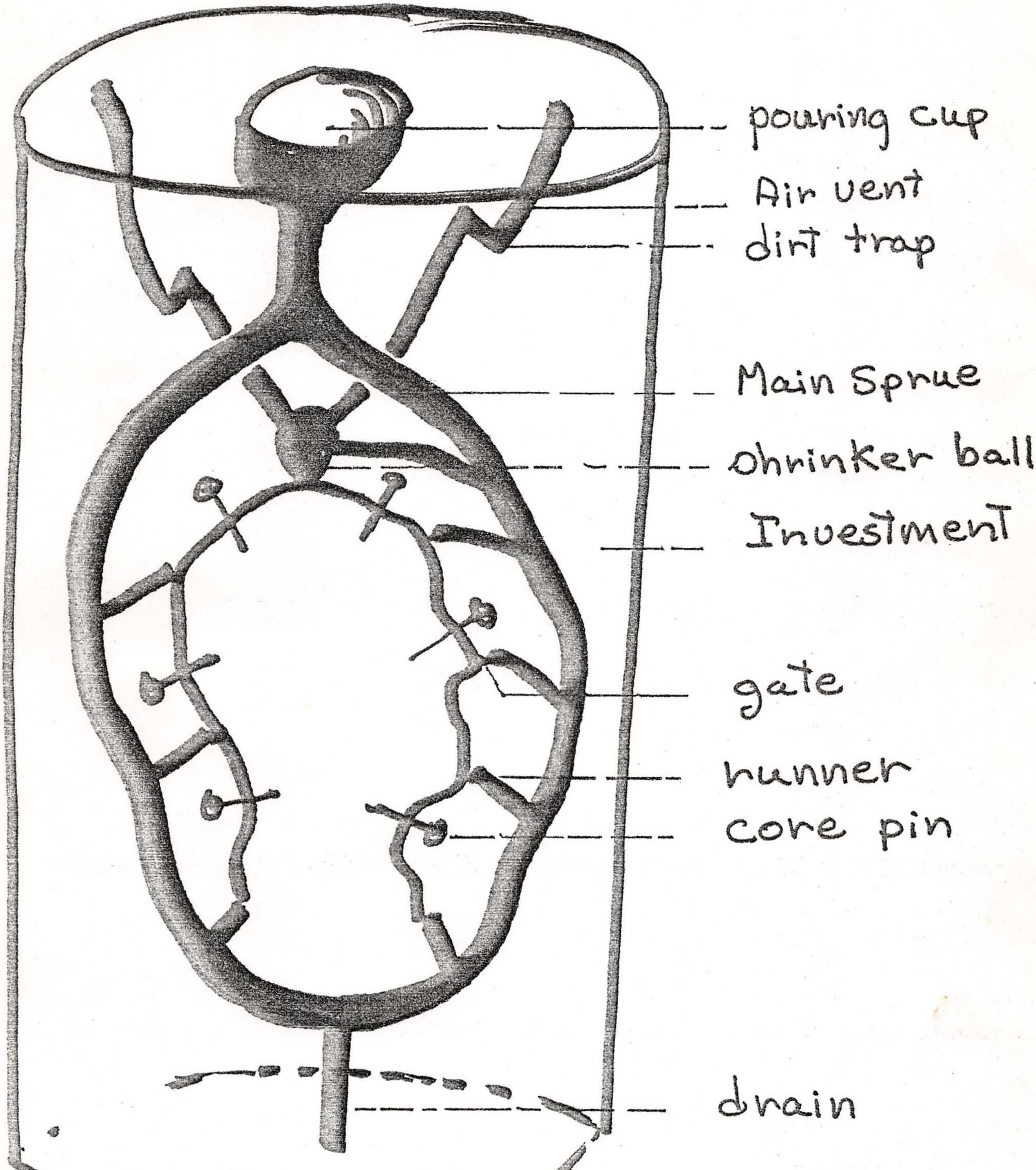

pouring cup
Air vent
dirt trap
Main Sprue
shrinker ball
Investment
gate
runner
core pin
drain

Fig. 6

The pouring cup should be of adequate width and depth to minimize the danger of hot metal spilling, as well as to reduce the loss of needed metal to fill the mold. Its size should be a minimum of 3 inches wide and 2 inches deep. The cup can be carved from or molded into the soft investment material.

As the metal is poured into the mold, the air-vents allow the gases and air to escape from within the mold cavity. The vents must always be attached to all of the highest isolated portions of the wax system, so that no air is trapped in the cavities as the metal is poured. Air vents should come out of the mold at least two or more inches away from the pouring cup, lest any spills from the pouring cup plug the air vents.

Because the air vent directly connects to the head, the dirt trap aids in preventing dirt or broken investment particles from falling into this head cavity.

The metal flows down through the sprue, reaches the bottom of the system and starts to flow upward throught the runners and into the head. The sprue should have at least twice the volume of the runners it feeds. For attachment, the sprue should be positioned at least an inch away from the sculptural from but not so far away as to make the mold excessively large - this would result in a waste of investment and make the mold heavy.

The shrinker ball is sometimes used at the top of a wax form to act as a reservoir of hot metal. Because of its larger volume, it feeds the hot metal back into the head as shrinkage occurs. Notice that a runner coming from the sprue connects to the ball. This positioning ensures that ~~that~~ the ball contains hotter metal than any area below it.

The investment or refractory material, surrounding the wax system is structurally weak after firing. It therefore should extend around the outermost wax area by at least an inch.

The gate is the point of attachment between the runner and the head. This attachment should be smaller in diameter than the diameter of the runner itself, thereby forcing or spraying the metal into the cavity or form. This minimizes any chance of shrinkage from the head back into the runner. The small diameter of the gate makes the runner easier to remove after casting. The gate's small diameter also ensures that the sprue system is kept full of molten metal, which reduces the chances of air getting into the head.

The runners or risers connect from the sprue to the head and feed the metal into the form as the sprue fills from the bottom. Each runner is always slanted upwards from the sprue. This ensures that the metal does not spill from the sprue into the form as it flows down to the bottom of the wax system. As a result of this arrangement, metal will only enter the runners as it rises up the mold, pushing all of the air out in front of it.

The core pins secure the outer investment to the inner investment, or core. The heavy core inside the head may need 8 to 10 eight penny nails to keep it in place when the wax is burned out. Pins are sometimes used in very small light cores. One should make sure that when a core pin is positioned, it is in a place where it is easy to remove and repair.

After it is melted in the firing, the wax runs out through the drain in the mold. Once the wax is gone, it furnishes a cavity, so the hot kiln air can circulate through the mold.

The following are some of the major considerations in setting up a sprue system:

*If possible, the wax used to make the sprue system should melt at a lower temperature than the wax in the sculptural form. This lessens the danger of cracking the mold from the expanding wax during the burnout cycle. This procedure also facilitates rapid drainage of the wax from the mold with less absorption of the wax into the investment mold.

*The diameter of the wax sprues should be greater than the thickness of the wax pattern section being fed.

*The length of the sprues and runners should be kept as short as possible, length being relative to diameter. The longer they are, the larger their diameter must be in order to prevent solidification of the metal in them before it reaches the form itself.

*There is no set formula for spruing. The number of sprues and their points of attachment to the form depend entirely on the shape and size of the form. Each separate heavy section of the form requires its own sprue, runner arrangement. Study the form very carefully to determine the best set-up for drainage, escape of gas and air through the vents, the placement of core pins and the even flow and solidification of the metal.

*Always construct the sprue system so that it is smooth and uniform, otherwise pieces of investment material may fall into the molten metal as it passes.

*Make the sprue system triangular or somewhat angular in shape instead of round. This prevents metal, when it is poured, from swirling and sucking in air.

*Some compromise will undoubtedly have to be made in the placement of the runners and core pins to facilitate metal flow and make the runners and nails accessable for removal and cleaning after casting.

Making the Sprues and Runners

(10) The triangular sprue can be cast in a one piece plaster mold. When pouring the wax into the plaster mold make sure that the wax is not too hot - wax will often burn and stick to the mold if poured under improper conditions The smaller round runners and vents can be extruded from a caulking gun or rolled out by hand.

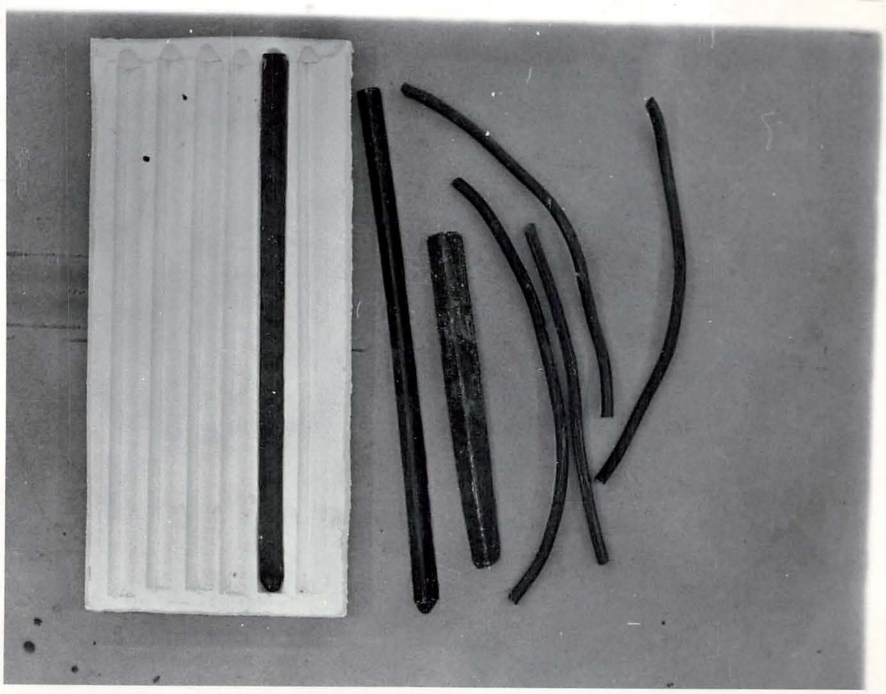


Plate 10

Examples of Sprue System

(11) The sprue system is set up in a manner similar to the diagram of the head. The metal is fed indirectly into the mold cavity from the bottom of the sprue and up through the runners. The core pins or nails, have already been pushed through the 1/8 inch thickness of wax. A ½ inch hole was made through the wax form so that the investment could be poured into the core. The hole was then covered over with wax to restore the original form.

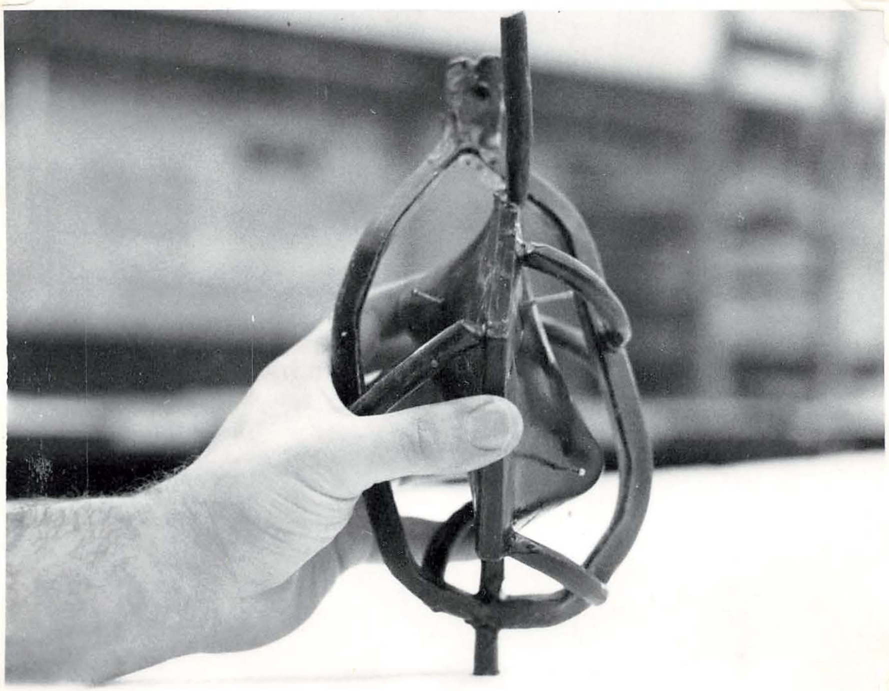


Plate 11

This method of prefilling the core works well if the core is small and light. As the weight and size of the core increase with larger sculptures, it is necessary to fill the interior core and outside investment at the same time so as not to collapse or burst the wax form. This can be done by cutting holes, one at the bottom and one at the top of the wax form to release the air. The core can then be filled at the same time as the outside when the investment is poured over the wax system. The holes in the cast form can be welded shut.

Plate 12

(12) This represents a simplified, indirect spruing method. One sees only two runners and they are at the bottom. The metal must run completely through the sprue and up the entire form before it solidifies. As long as the form is small and the metal is poured at a high temperature, this method works very well. Additional runners, although they are not always needed, ensure that the form will fill completely before solidification of the metal. It has been said, that if in doubt about the distance the metal will flow, sprue it.

Plate 13

(13) Shown here is the direct method of casting. The metal is poured directly into the form and only one vent and drain have been added. This system when cast, filled perfectly. After cleaning the metal, however, it could be seen that small particles of investment had broken off into the molten flow causing pits and blemishes on the bronze surface. This occurred because of the extreme agitation of the metal when it entered the mold and the air tried to flow out. It is likely when using this method that areas of investment wash out or break away because the metal must always flow over the same surface until the entire mold is filled.

INVESTMENT

Types of Investment

The investment must be able to withstand the temperature and pressure of the bronze. Plaster is used as a binder. Material such as sand, grog or silica flour are added to the plaster to withstand the thermal shock. There are many mixtures that work well. The most widely used is 1 part plaster, 1 part silica flour and 1 part sand.

Other mixtures that I have tried are as follows:

1 plaster - 1 silica flour - 1 silica sand: This mixture works very well and should be considered basic.

1 plaster - 2 silica flour - 1 silica sand: Because of the additional flour, the investement was slightly chalky and more prone to cracking.

1 plaster - 2 silica flour: This mixture proved to be too chalky and soft. The sand is needed to add a binding strength.

1 plaster - 1 silica flour - 1 grog (ground up fire brick): The grog proved to be superior to silica sand because its particles were angular and sharp and gave the mixture a better cohesive strength. Silica sand particles are round and smooth. A drawback to grog is that it is four times more expensive than silica sand.

1 plaster - 1 silica flour - 1 silica sand - 1/3 of 1 Hydracal: Hydracal is a very strong gypsum cement. I had hoped that it would furnish more strength than just plaster but after firing it proved to be much weaker than plaster alone.

1 plaster - 2 silica sand: This mixture was somewhat brittle and cracked, if handled carefully it could work well. Clean washed sand from the gravel

pit worked as well as the silica sand.

Fibrous materials can also be added to the mixture to add strength. Commercial investments add small amounts of fibrous talc or asbestos to the basic mixture.

Luto can be used with the basic mixture. It is previously used or fired investment material that has been crushed up and sifted. As Luto already contains the basic mixture minus the binding power of plaster, it can be substituted in part for sand and flour. The normal setting time of the basic investment is 15 to 20 minutes. When Luto is used, the setting time drops to about 4 minutes.

When working with any investment material, always wear a dust mask.

Water constitutes about 40% of the investment material mixture, or about 3 of 7 parts of the investment material. Water is placed in the container first. The plaster is slowly added, followed by the silica flour and then the sand. Let the mixture stand to soak for a minute and then mix slowly by hand until it is of uniform consistency. If the consistency is too thin, the sand will settle to the bottom. If it is too thick, it will not pour well and will not properly coat the wax system.

Investing the Wax

Plate 14

(14) It is a good practice to prepare the wax surface by painting on a thin mixture of 1 part liquid soap and 3 parts alcohol. The alcohol will cause the mixture to dry quickly and the soap will lessen the chances of air bubbles adhering to the wax surface when the investment is poured.

(15) The wax system is mounted on a clean surface. The two wax systems on the left are supported by a small mound of investment which has been thickened with luto. The two on the right were able to support themselves by their sprue systems, which were stuck to the table top with hot wax.

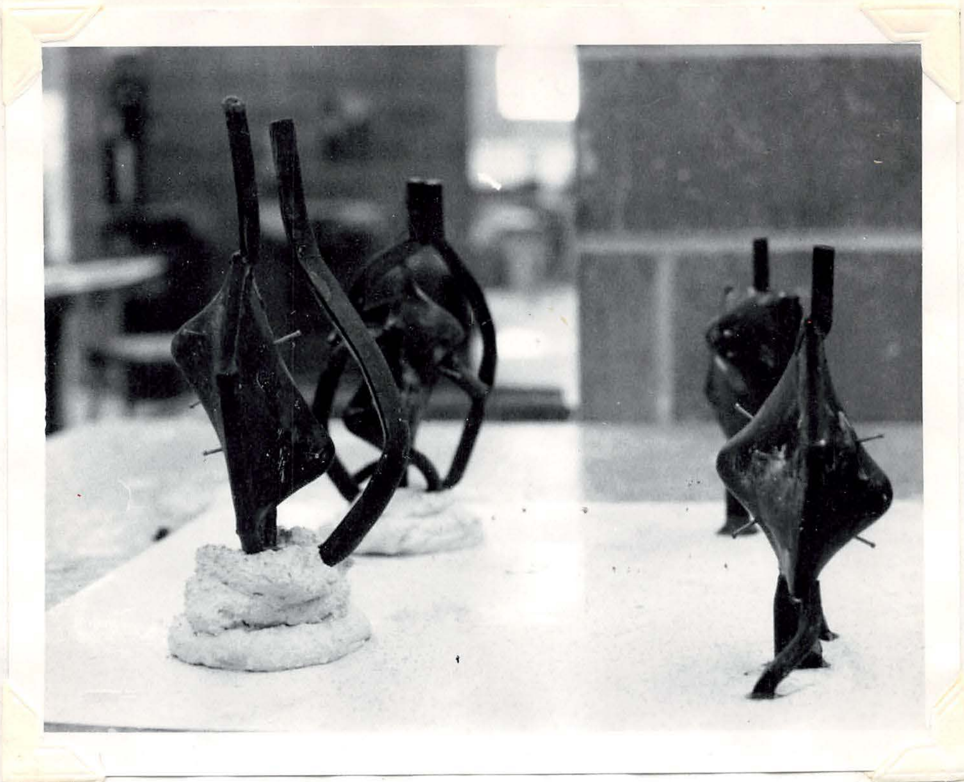


Plate 15

(16) A wire mesh or chicken wire is placed around the supported wax form. This structure reenförces the fragile investment.

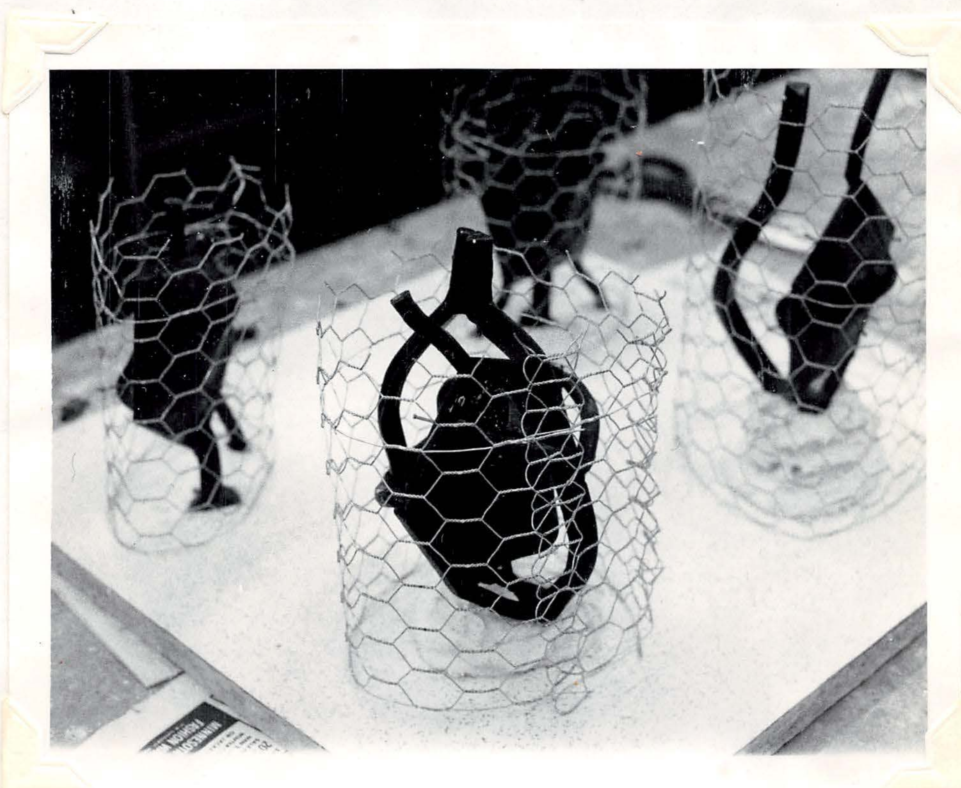


Plate 16

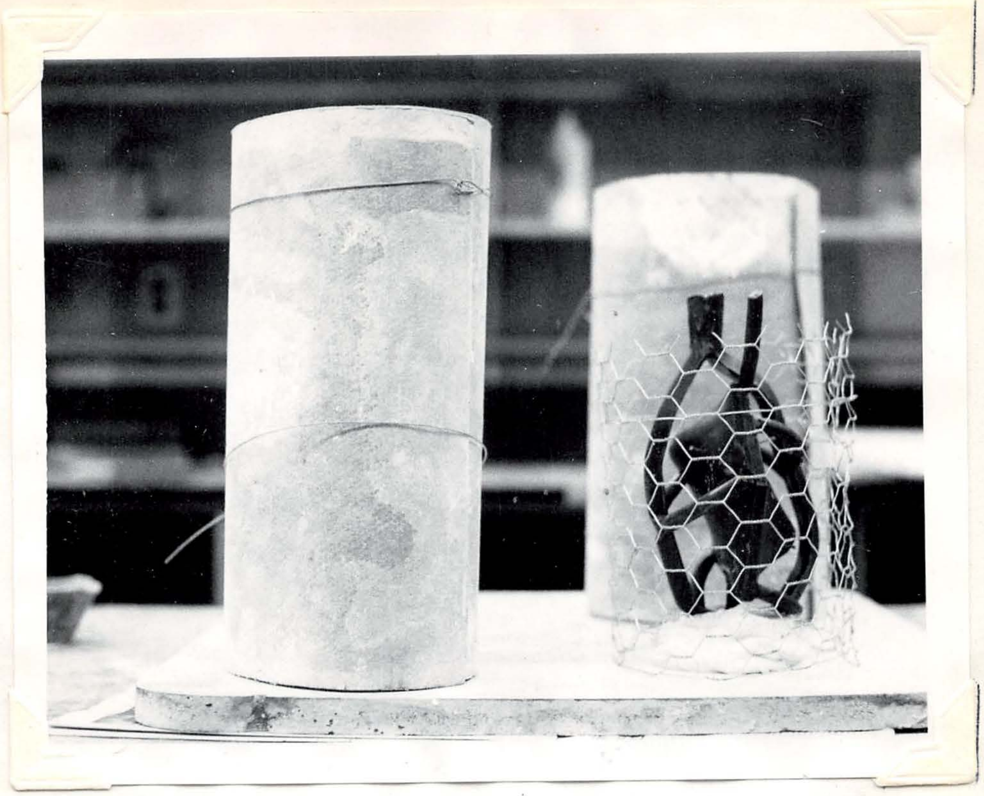


Plate 17

(17) A strip of linoleum or tin is placed around the wire to contain the liquid investment.

(18) Wire is wrapped around the linoleum and clay is pressed around the bottom to keep the investment securely contained. The investment can now be mixed and poured. Try to pour the investment down the edge of the container in such a manner so as not to mix air bubbles into it, or break down the wax system.

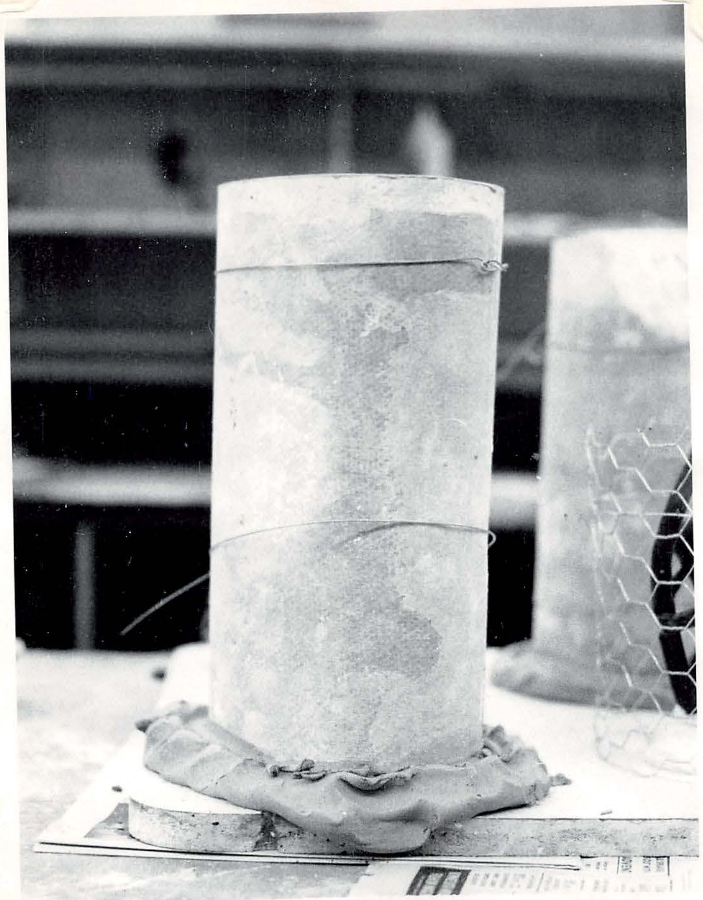
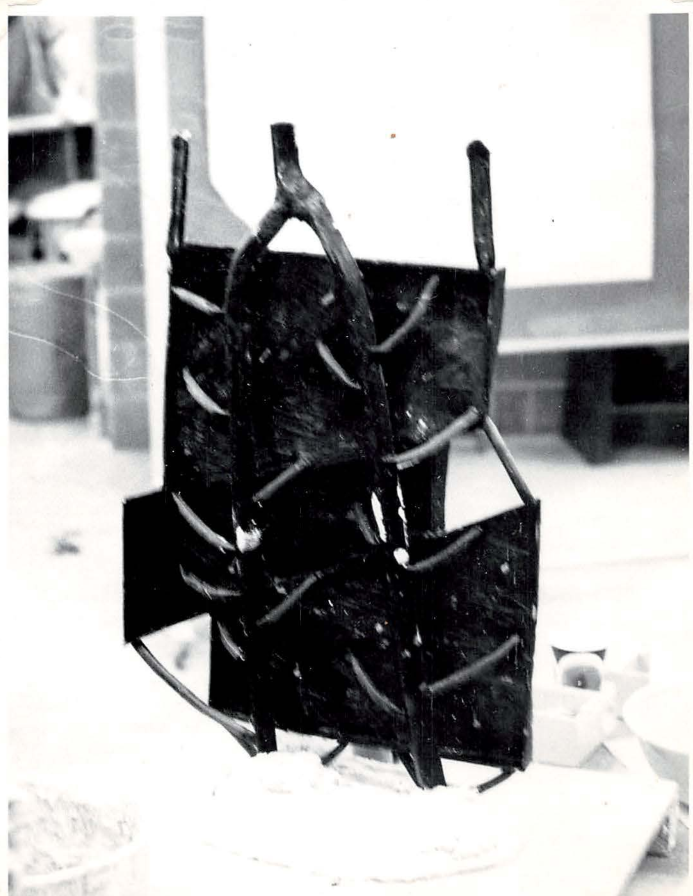


Plate 18

Plate 19



(19) Another method of investing was used on this irregularly shaped relief.

(20) A luto wall was built up around the entire piece, almost to the top. It is an inch in thickness and to within a ½ inch from the inside wax. By being able to use luto and produce an investment mold that exactly follows the contour of the wax system, this method wastes very little material. To make the wall, a basic batch of investment is made. Luto is added until the mixture is thick enough to be manipulated into a wall. The small sticky luto locks are laid one upon the other until the wall is made. As this mixture hardens quickly, many small batches should be made. When the wall is hard, a layer of chicken wire is wrapped and tightened firmly around it.

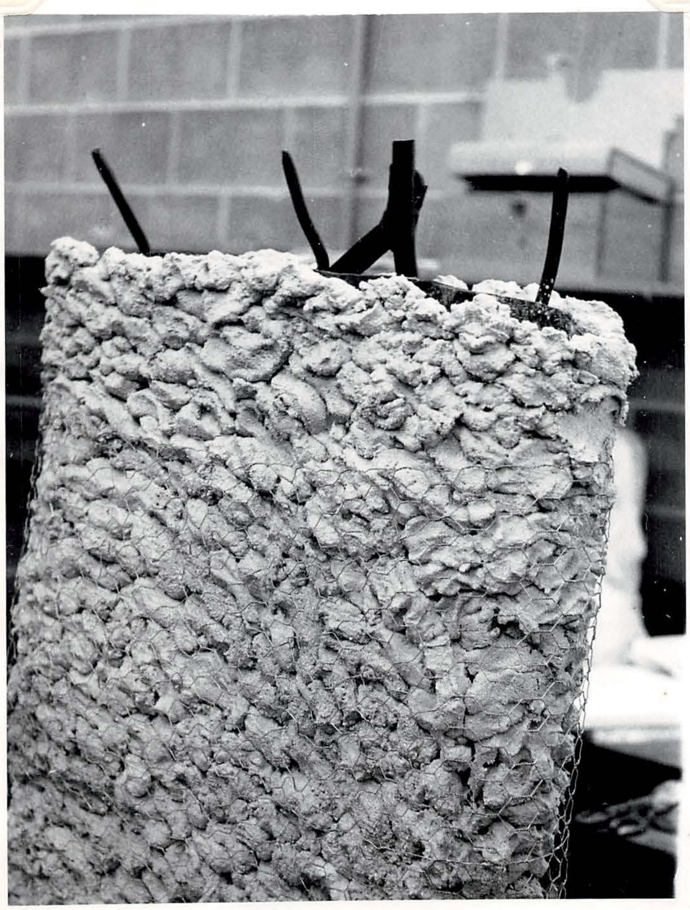


Plate 20

Plate 21

(21) The whole surface is covered with more of the same investment until all of the holes are filled and the chicken wire is securely covered.

(22) Enough basic investment is mixed to fill the mold cavity and "cap off " the top of the mold. This mixture does not contain the luto, which accounts for its lighter value in the photo.

(23) A pouring cup is carved into the investment. the drain and vents are scraped clean.

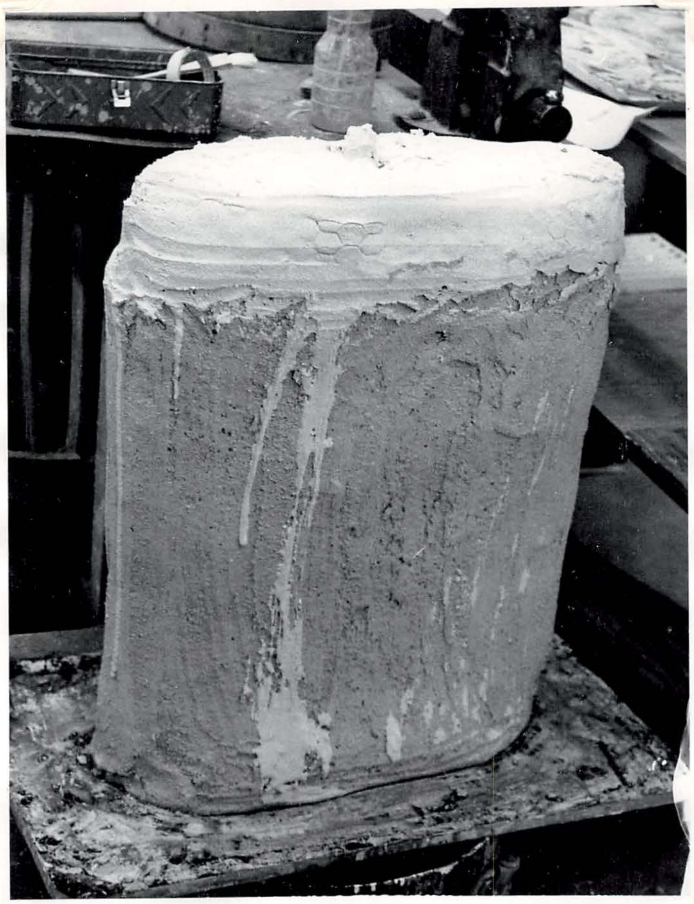
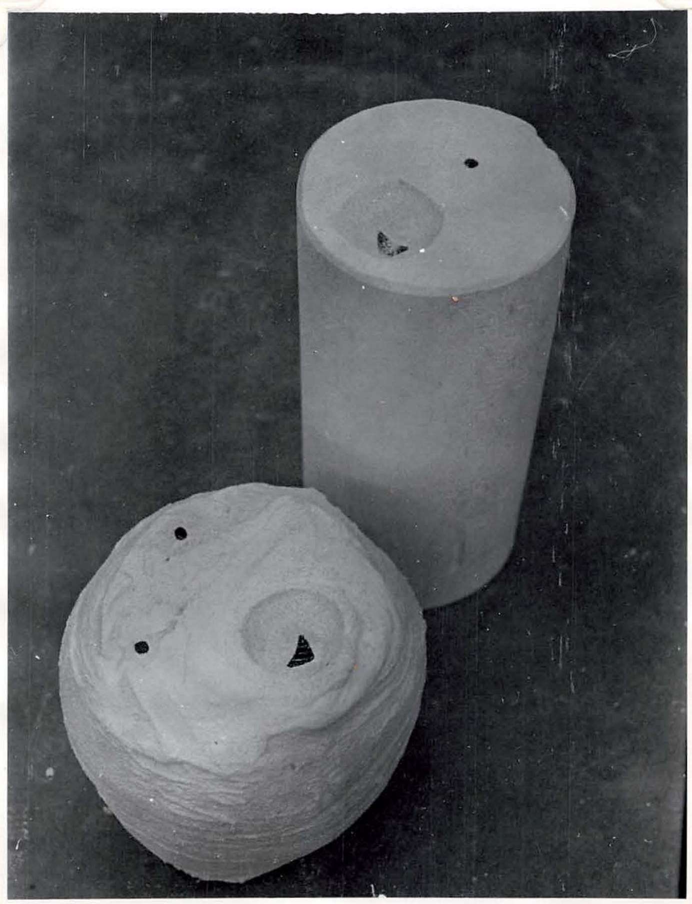


Plate 22

Plate 23



(24) The molds are loaded into the kiln for wax burn out and curing. If the mold has been allowed to dry for several days, it should be wet down with water. This assures that as the kiln temperature rises, the wax will run out of the drain rather than be absorbed into the investment. In most cases the molds are supported on bricks. Angle irons are run under the drains and out of the kiln to remove the molten wax.

Plate 24

This is done so that all of the wax does not burn up inside the kiln, prolonging the firing and producing unnecessary soot.

Plate 25

(25) The fire bricks are placed tightly together around the mold to form a kiln, the lid of the kiln secured. Any loose investment or dirt around the pouring coup is vacuumed away. This same cleaning should also be done after the firing cycle.

THE BURNOUT

The ideal temperature to be reached is 1000 degrees F. When reached, it can be held until total wax burnout occurs. The investment itself is dry at 500 degrees. The higher temperature is needed to burn off all of the wax residue.

The length of the firing cycle depends greatly upon the thickness of the molds. Generally, burnout takes between 24 and 48 hours. Burnout need not neceessarily be complete at reaching 1000 degrees F. If there is any visible burning or dark soot around the pouring cup, the temperature should be held until the burning stops and the dark soot changes to a white ash. The kiln is turned off and allowed to cool slowly to about 300 degrees F. Later it is dismantled. The molds are ready to be buried in the sand pit for casting.

PACKING THE MOLDS

The sand in the casting pit aids in supporting the fragile investment molds during pouring. Plain sand will not be firm enougb to furnish the support. The sand is mixed with small amounts of fine clay and ball clay. Some naturally occurring sands do have the necessary cohesive quality. To be always ready for casting, the sand should be covered and kept moist. Too much moisture in the sand could cause the water to soak into the mold and come in contact with the molten metal. Too little moisture will keep the sand from packing properly. The right amount of moisture should just hold the sand together when squeezed in one's fist. A hole dug in the sand pit accomodates the largest mold. The smaller molds are added, the sand being built up until the tops of all of the molds are at the same level. The sand is not packed all at once, but in layers of one or two inches at a time. This ensures the mold's firm encasement by the sand.

When packing, areas around the bottom of the mold deserve special attention. They are likely places for the metal to exert pressure and burst through the mold. The sand can be packed by foot, or with small lengths of wood or pipes to make it firm. When packing, one should not hit or pat or do anything which might damage the mold.

(26) The sand has been packed to the top of the molds. During the entire process the pouring cup and air vents should be covered with a paper and a brick to prevent spillage of sand into the mold's cavities. Before casting, the covers are removed.

Plate 26

MELTING AND POURING

The Care and Use of the Crucible

Crucibles are made of two basic compositions - the clay graphite-ceramic bounded and the silicon carbide bonded type. Both use the refractory materials graphite and silicon for heat conduction and for structural strength. Due to its greater heat conductivity and its greater strength, the silicon carbide crucible is the most desirable. Either type of crucible can be used for melting bronze. However, different metals should not be melted in the same crucible. This practice will cause contamination in the melt and make it difficult to get a good casting. A different crucible should be used for each metal melted.

In the care of the crucible, several factors are important. Before use, inspect each crucible for cracks and damage. New crucibles should be properly annealed before use. Annealing relieves all strains set up during the manufacturing process. Full elastic properties to withstand thermal shock are also developed. To anneal the crucible, make sure it is dry and then place it in the furnace. Adjust the burners to idle, or the lowest heat for the first 10 minutes. Increase the burner setting gradually to raise the furnace to a red heat. The total heating period should be about 45 minutes. After this the crucible can be put into use.

Charging the Crucible with Bronze

The crucible is charged with metal before the furnace is started. Sprues or clean scrap are charged first, while ingots or bars are charged last. Never wedge metal tightly into the crucible, as the crucible may crack as the bronze expands in heating. Any metal added to a molten mass should be dry, or an explosion may occur because of the steam generated. Ingots should be thoroughly dry, and added gently to the molten charge with tongs.

Preheating Charge Bronze

It is not a good practice to preheat scrap or bars by placing them across the exhaust port in the lid of the furnace, or on the lid. The metal may melt or pieces may fall in, allowing molten metal to run down inside the furnace lid and walls. The metal is oxidized very rapidly and attacks and deteriorates the refractory furnace lining. Ingots and scrap can be placed around the lid for preheating well away from the exhaust port.

The Curcible Rest

The crucible rest supports the crucible on the floor of the furnace. It is usually of the same material as the crucible. The rest positions the crucible at the proper height in the combustion chamber and prevents it from contacting the cooler furnace floor. The diameter of the rest should be slightly larger than the bottom of the crucible. At times it is difficult to separate the crucible from the rest. A separating material such as a sheet of corrugated card board can be placed between the two before the furnace is started. After it burns, the remaining carbon will make separation easier.

The Crucible Tongs and Shank

The crucible of bronze is lifted out of the furnace and held for pouring. Crucible tongs and shanks are tools necessary for handling the crucible during melting and pouring. The tongs are used to place the crucible in the furnace and to withdraw the crucible of molten metal at the close of the melting period. After the crucible has been with drawn from the furnace, it is placed into a pouring shank, or holder, which aids in pouring the metal into the molds. Both tools should fit the specific size of the crucible being used. This prevents damage to the crucible. Hazards related to melting and pouring bronze are minimized by proper use and understanding of the crucible tools.

Melting the Bronze

Preheat the melt on low for about 10 minutes. After this warm up stage, the burner can be adjusted to maximum until the atmosphere is slightly reducing, with stringers of flame in the exhaust. Then the fuel should be closed to a setting where traces of flame just disappear. The burner should be adjusted to develop as close to a neutral atmosphere as possible, so combustion is completed within the melting chamber of the furnace. For best furnace performace, the air valve should be adjusted to the full open position. It is very important to remove the residual moisture, grease, oil and other organic substances prior to charging. These contaminating materials, at high temperatures, give off water vapor, carbon monoxide, hydrogen, and carbon which are absorbed directly into the molten metal. Over heating the melt should be avoided. The possibility of gas absorption increases with higher temperatures. Pouring temperatures for different alloys vary. One should never exceed by 100 degrees the correct pouring temperature.
The residual heat of the metal mass and crucible will be enough to sustain the temperature through pouring. Equally important is the amount of time spent in the furnace. Once the melt has reached temperature for removal, it should not be retained in the kiln. Holding a heat in the furnace exposes the metal to the oxidizing effects of the atmosphere. When pouring the metal into the mold, it should be done smoothly and without any interval.

Illustrations of the Pour

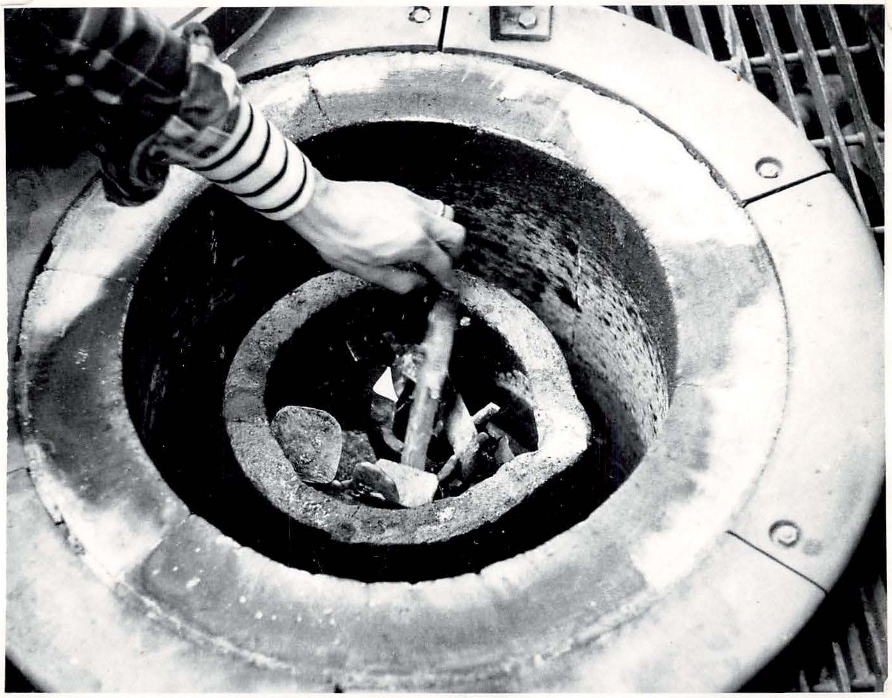


Plate 27

(27) The clean scrap is added prior to starting the furnace. One should not wedge the material in tightly nor let it rest above the top of the crucible

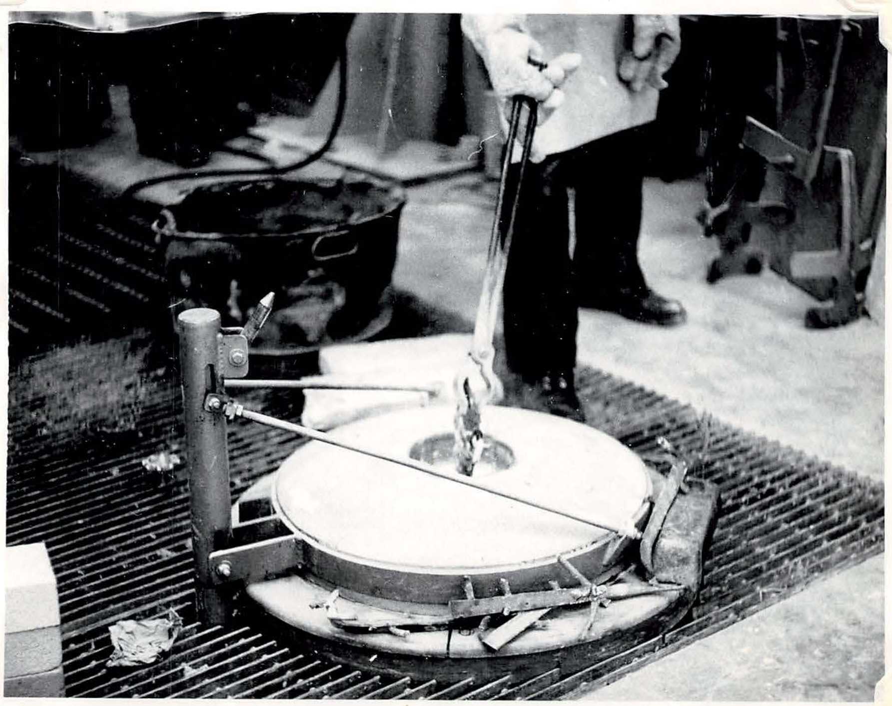


Plate 28

(28) The furnace is started. The remainder of the metal is added through the port of the lid with tongs. Some scraps and ingots are preheating on the edge of the kiln.

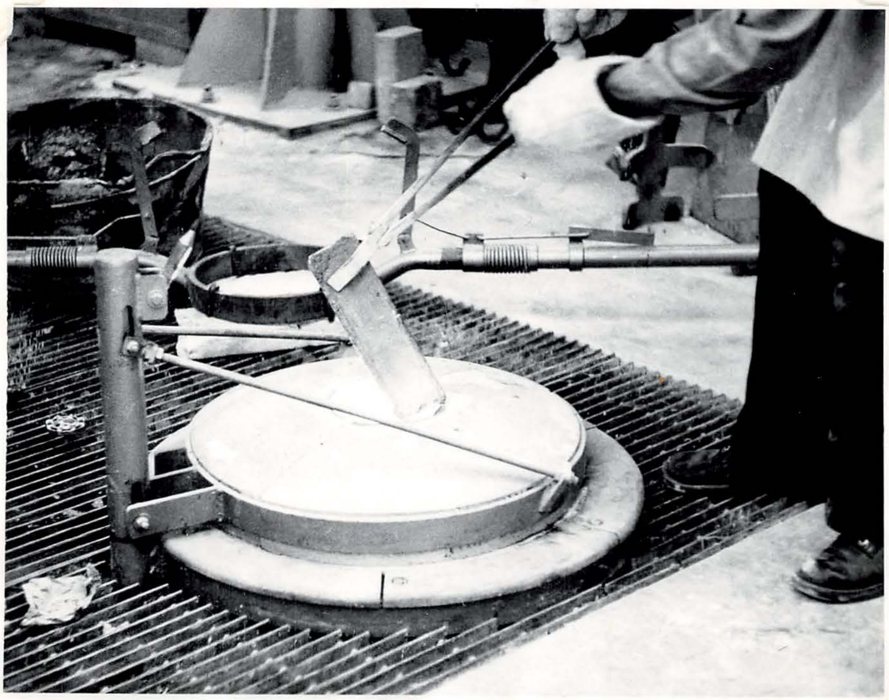


Plate 29

(29) As the melt progresses, the last ingots are carefully added; they should not be dropped into the crucible.

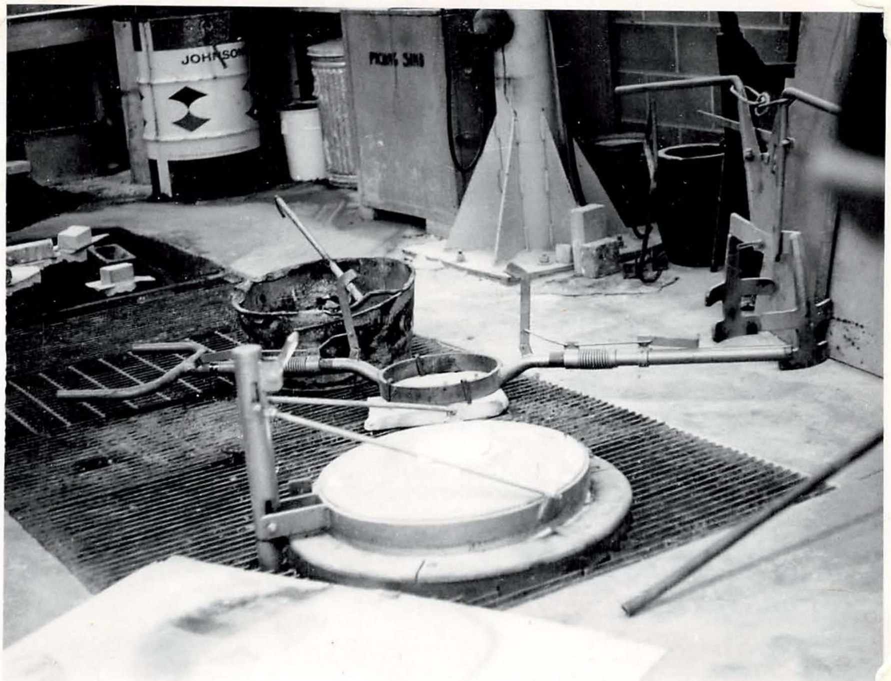


Plate 30

(30) The melt takes about one hour. During this time the molds have been packed and are ready to pour.

Plate 31

(31) After an hour has gone by, the temperature is checked with a pyrometer. Insert the bottom part (below the weld mark) of the pyrometer into the metal. Before it is put directly into the molten mass, allow the temperature to rise to 500 degrees F.

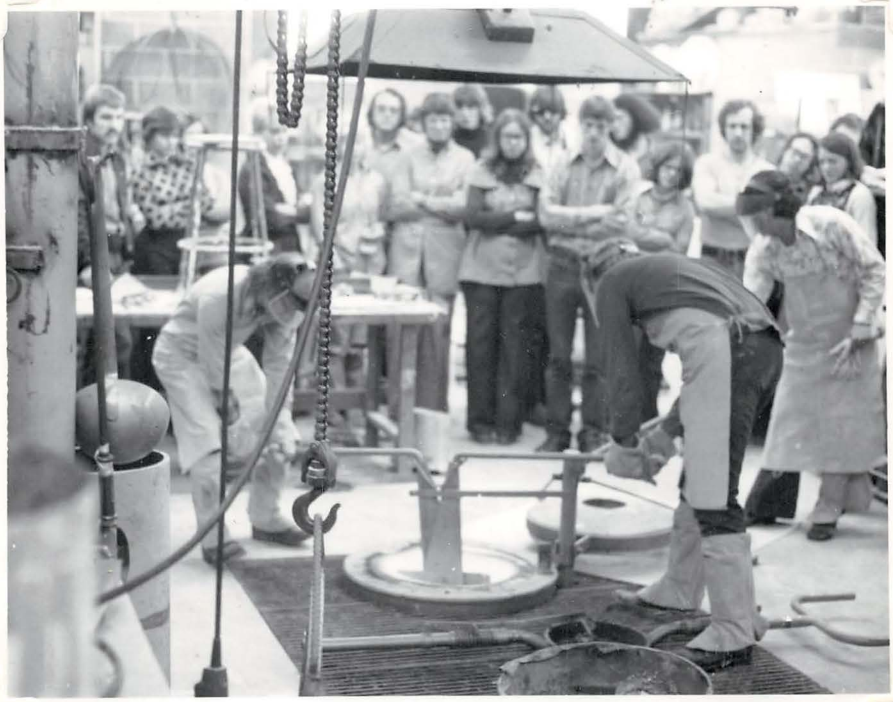


Plate 32

(32) The lid of the kiln is opened and the crucible tongs used to lift out the crucible, which is then placed in the pouring shank. Each member of the pouring crew wears safety gear - a long sleeved shirt, an apron, asbestos gloves, leggings and a face viser. Because of the extreme weight, the hoist is used in this pouring. The slag is being skimmed off of the metal.(33)

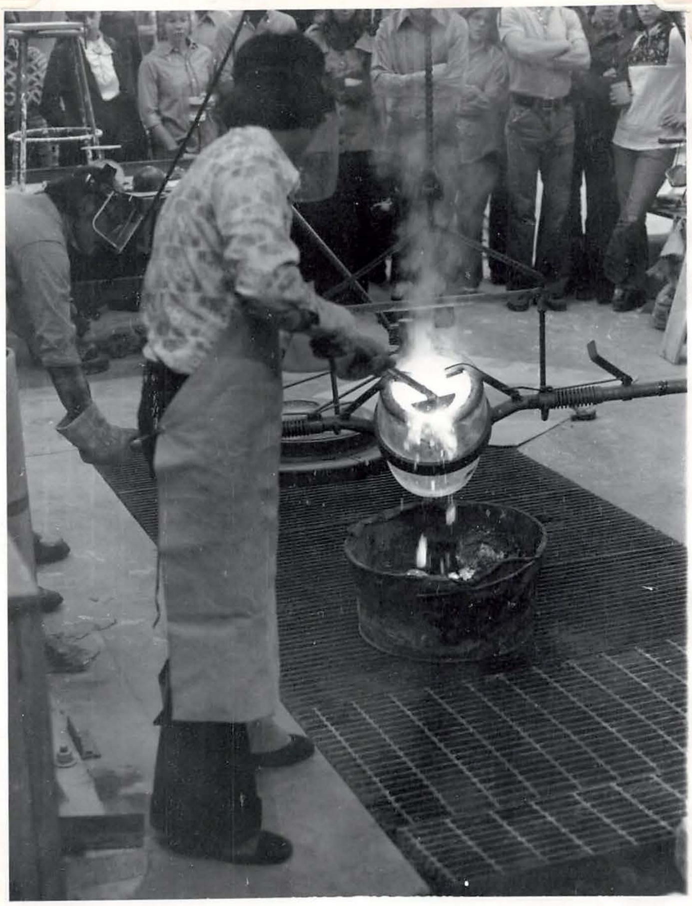


Plate 33

Plate 34

(34) The crucible is guided to the mold and the metal poured at a moderate speed. One should try not to spill and keep the pouring cup full until the metal can be seen to rise out of the air vents. If any metal is left in the crucible after the casting, it is poured into an ingot mold, or pocket made in the sand.

Plate 35

(35) Before placing the crucible back into the furnace, the slag is scraped from its walls and bottom.

Plate 36

(36) The crucible is placed back into the furnace and allowed to slowly cool

Plate 37

(37) After about 15 minutes the molds can be removed. All of the sand is remoistened, cleaned of investment and placed back into the pit.

Plate 38

(38) The wire on the mold is cut and pulled off. The investment usually breaks away.

Plate 39

(39) The bronze can be tapped with a hammer to knock off any remaining materials, then cooled in water which further cleans the metal.

PATINATION

Bronze has been gilded with gold, notably by the Greeks, silvered, embellished by the use of enamels, and inlaid with other metals by the Egyptians, Assyrians, Greeks, and Persians. It has been electroplated and camouflaged by patination. Some sculptors even attempted to use the clean, golden color of the metal itself.

We have a long historical tradition of placing immense value on items from antiquity. Many bronzes from the past have obtained a rich patina through their aging. The natural aging process of bronze has resulted in the practice of making sculptures look old, of antiquing them. One should not dismiss the worth of this endeavor. A sculptor is not just antiquing, but recalling the long and rich heritage of bronze work. Emulating or reiterating the past is much a part of contemporary sculpture.

Another approach to patination is the technical one. Here the sculptor can explore three different surfaces. First, a surface could remain just as it came from the casting, usually being covered by a brown mottled fire scale. After the sprues are cut off bright spots are on the surface. The surface would remain this way. A second approach would be to tone down the bright spots to match the fire scale. A third method would be to brighten up the whole surface until none of the "clean up" blemishes showed. The technical approach is simple, direct and expresses the "cast" character of the metal.

The last approach involves a patina, or any surface that best integrates the form and context of the sculpture. Seemingly, this is the most pragmatic approach.

The choice of final color or surface treatment remains with the sculptor. A purist would have no ground to stand on, because the color and appearance of the bronze is in a constant state of change through oxidation. Therefore, it is misleading to assume that there is a color or surface that the metal should have.

To seek integrity for the surface of the sculpture then, is not to decide if there should be a patina or not, but rather what the sculptor feels to be the adequate, integrating patina that will harmonize with his sculptural form.

Patina Application

When applying a patina, it should be kept in mind that some of the gases released are toxic especially if the chemcial contains a chloride which can break down into chlorine gas. One should make sure that the area is well vented.

There are three methods of patina application - cold and hot application with a brush, or dipping and by fuming the surface with chemical vapors. The same chemicals can react quite differently in each case. Fuming can be very time consuming and at the mercy of many variables, so discussion here will mainly pursue the direct application methods.

Before patination, the surface of the bronze should be cleaned with a mild solution of nitric acid. It should then be wire brushed under running water to further clean the surface and remove any acid residue. Sand blasting the surface works well also, but may tend to mute some of the surface detail.

The patina solution is brushed over the entire surface and allowed to dry. Faster drying and more stable colors can be facilitated by use of a torch. As the bronze gets hotter and more applications of the solution are made, the patina becomes more substantial and opaque. The application process can be stopped at any time depending, upon the desired patina. After the application is complete and the bronze has cooled, the surface can be rubbed with paste wax, or a beeswax- kerosene solution. This application will bring out the color and protect the surface from undergoing any further change through oxidation.

Ferric nitrate and ammonium sulphide are common compounds that are readily available and easy to work with. Once applied they are fairly stable and will produce a wide range of colors.

Ferric, or iron nitrate can easily be made with nitric acid and nails. Place about a pound of nails in a two quart glass jar. Add to this about a one inch depth of full strength nitric acid. No severe reactions will occur in the absence of water. Then add two cups of water. Be sure to do this outside in an open area, as noxious ,gases are given off in the chemical reaction. After the bubbling and fuming have stopped, fill the jar with water and let stand for 24 hours. The nails can then be removed and the remaining brown sludge used as ferric nitrate. For use, the sludge is again diluted with 5 to 10 parts more water, or unitl one finds the solution working to satisfaction.

Slowly brush the ferric nitrate on the cool bronze surface. It will begin to yellow the metal. As heat and more applications of the solution are made, the patina will build up and intensity, going through color stages of tan to brown. When more heat is applied, the brown will turn to a cordovan red. Even shop dust can be collected and applied with the solution to change and mottle the color.

Ammonium sulphide can be used in conjunction with ferric nitrate to achieve blacks or shaded areas on the bronze. The ammonium sulphide should be diluted with water to change its color intensity.

The previous technic represents only a minute portion of the vast multitude of combinations and intricacies of patination. Following are 21 basic formulae for patination.[8] Most can be applied cold or built up through the addition of heat.

21 Patina Formula

1. Blue

Sodium Hyposulphite	60 Grams
Nitric Acid	4 Grams
Water	1 Quart

The Metal should be dipped into the solution.

2. Yellow Green

	Parts By Wt.
Sodium Thiosulphate	1
Iron Nitrate	8
Water	128

The solution is brushed on clean surface until a crusty green appears. (An inexpensive paintbrush is recommended since it will have to be discarded after use. Afterwards dip the bronze for six minutes in diluted nitric acid. Remove the bronze, wash and dry.

3. Brown

The recipe is the same as the former, the only difference being the length of time brushing the solution on. In this case, brush until brown appears.

4. Antique Green

One Quart of Water	40 Grams
Cupric Nitrate	40 Grams
Ammonium Choloride	40 Grams
Calcium Chloride	40 Grams

5. Matte Brown

Barrium Sulphide	1 ounce
Potassium Sulphide	¼ ounce
Ammonia	2 Fluid ounces
Water	4 to 5 Quarts

6. Yellow Green

	Parts by Weight.
Ammonium Chloride	7
Copper Acetate	4
Water	8

Brush on to surface.

7. Light to Dark Brown

Ferric Nitrate	1 Teaspoonful
Water	½ Quart.

(7 Continued)
Heat the Bronze and apply the liquid.

8. Brown to Black

	Parts by Weight
Antimony Sulphide	2
Sodium Hydroxide	4
Water	255

Heat the liquid and apply.

9. Brown to Black

Potassium Sulphide	A few crystals
Water	½ Quart

Heat the liquid and apply.

10. Early Stage of the following recipe is purple.

11. Additional application and chemical action turns the bronze light green.

	Parts by Weight
Sodium Chloride	5
Ammonia	4
Ammonium Chloride	5
Glacial Acid	4
Water	32

Brush to surface

12. Antique Green

		Parts by Weight
C	Copper Sulphate	12
	Ammonium Chloride	2
	Water	125

13. Black

	Parts by Weight
Copper Carbonate	2
Ammonium Carbonate	4
Sodium Carbonate	1
Water	32

Heat the solution to a boil. The bronze should be immersed. The solution should b e stirred.

14. Green

Cupric Nitrate	1 teaspoonful
Water	½ Quart

Heat the bronze and apply the solution

15. Brown to Black

Ammonium Sulphide	1 Teaspoonful
Water	½ Quart

Heat the bronze and apply the solution.

16. Antique White

Bismuth Nitrate	2 Teaspoonfuls
Water	½ Pint

Heat the bronze and apply the solution.

17. Verde

	Parts by Weight
Copper Nitrate	1
Ammonium Chloride	1
Calcium Chloride	1
Water	32

Immerse the bronze into solution until dull green appears.

18. Golden Yellow

Sodium Thiosulphate	¼ Ounce
Ferric Nitrate	2 Ounces
Water	1 Quart

Heat solution to a boil. Dip bronze object.

19. Blue

Potassium Sulphide	15 Grams
Ammonium Chloride	200 Grams
Water	1 Quart

Brush to surface.

20. Deep Rust Red

Copper Nitrate	48 Grams
Sal Ammoniac	48 Grams
Calcium Chloride	20 Grams
Copper Sulfate	10 Grams
Oxalic Acid	10 Grams
Water	4 Fluid Ounces

Brush to surface for the color. Then dip into diluted nitric acid solutions (one part acid to 8 parts water) for one half hour, remove wash and dry. In the above, the wrong combinations will give a deep dark green.

21. Blue Green

	Parts by Weight.
Copper Sulfate	5 Ounces
Cupric Acetate	5 Ounces
Copper Carbonate	5 Ounces
Water	128

Dip the bronze into the solution.

SUMMARY

I hope this paper will aid the beginning student and introduce him to the possibilities of bronze casting by the lost-wax method.

There are numerous books and publications on the methods of bronze casting. Many of them are conflicting and out of date. This paper draws upon their concurrencies, and tries to simplify their conflicting ideas. The chapters dealing with the sprue system and types of investment should be regarded as experimental on my part. There are many ways to approach these technics; they can be further explored through reading and experimentation.

Most of my experience has not come through reading, but from working in a foundry. For that experience I wish to thank Paul Granlund, sculptor, with whom I worked for a year; and Boyd Christensen, sculptor and instructor at the University of Minnesota in Duluth.

- FOOTNOTES -

[1]John Mill, Studio Bronze Casting: Lost Wax Method (New York: Praeger, 1970), p.1.

[2]Ibid.

[3]Sculpture Casting Conference, First Conference Proceeding. (Kansas, 1960), p.14.

[4]Jules Struppeck, The Creation of Sculpture (New York: Holt, 1952), p. 89.

[5]Third Casting Conference (1964), p. 28.

[6]Carl Clarke, Molding and Casting (Maryland: Standard Arts Press, 1946), p. 47.

[7]Ibid., p.57.

[8]John Brzostosk, "The Patination of Bronzes," Craft Horizons, (Nov./Dec., 1965), p. 34.

B I B L I O G R A P H Y

Baldwin, John. Contemporary Sculpture Techniques.
New York: Reinhold, 1967.
This book does not directly cover lost-wax casting, but contains many related and applicable areas.

Brzostoski, John. " The Patination of Bronzes," Craft Horizons, (Nov./Dec., 1965).

Burnham, Jack. Beyond Modern Sculpture.
New York: G. Braziller, 1969.

Campbell, L. and Millikan, Moria. "The Craft of Bronze Casting." Craft Horizons, (Jan/Feb., 1963), 26-34.
This is a very good article; much of it is a summation of the 1962 Bronze casting conference in Kansas.

Casson, Stanley. The Technique of Early Greek Sculpture. New York: Hacker Art Books, 1970.

Choate, Sharr. Creative Casting.
New York: Crown Publishers, 1966.
This is a very comprehensive book on casting, but deals mostly with jewelry and precious metal casting.

Clarke, Carl. Metal Casting of Sculpture.
Butler, Maryland: Standard Arts Press, 1948.
This is a very good foundery manual, although somewhat outdated.

Clarke, Carl. Molding and Casting.
Maryland: The Standard Arts Press. 1946.
This is one of the finest books dealing with mold making and plaster technics.

Clarke, Geoffrey. A Sculptor's Manual.
New York: Reinhold, 1968.
Chapter 2 deals with foundery methods and briefly introduces some new methods.

Cody, Edwin. Precision Investment Casting.
New York: Reinhold, 1948.
This book is for industrial casting, but has some useful tables and information.

Coleman, Ronald. Sculpture. A Basic Handbook for Students. Iowa: Wm. Brown Co. 1968
A very good guide for the beginning caster. It contains good illustrations, and the text is easy to follow.

Engineering Societies Library. Bibliography on Precision Casting by the Lost-Wax Process. New York, 1949.

Harvey, T. Fundamentals of Investment Casting. Indianapolis: U.S. Naval Technical Publications, 1958.
This book is an engineers manual used for industrial applications. It contains useful information on the properties of the various investment materials.

Hoffman, Malvina. Sculpture Inside and Out. New York: Van Nostrand, 1970.
This book contains very good illustrations of the lost-wax process and the text is short and precise.

Investment Casting Institute. Investment Casting Engineering and Design Manual. Chicago: Investment Casting Institute, 1957.

Irving, Donald. Sculpture; Material & Process. New York: Van Nostrand, 1970.
This is a very good, well illustrated technical manual. Chapter 6 (on lost-wax casting) is excellent.

Miller, Alec. Tradition in Sculpture. New York: The Studio Publications, 1949.
The book attempts to look at the "high points" in the history of sculpture with the view of a craftsman rather than an art historian.

Mills, John. Studio Bronze Casting: Lost-Wax Method. New York: Praeger, 1970.
This manual is probably the foremost book on the lost-wax process.

__________. The Technique of Sculpture. New York: Reinhold, 1965.
Chapter 9 contains a condensed version of Mill's other excellent book

Putnam, Brenda. The Sculpture's Way. New York: Watson-Guptill Pub., 1948.
This is a very good guide to mold making and is well illustrated.

Rich, Jack. The Materials and Methods of Sculpture. New York: Oxford University Press, 1947.
Chapter 6 is an excellent guide to metals and their properties. It has few illustrations, but has a very comprehensive text on metal technics.

Savage, George. A Concise History of Bronzes. New York: Praeger, 1968.
It presents a 4,000 year history of bronze sculptures. It also contains information on early casting methods.

Sculpture Casting Conference. Proceedings of the First Conference. University of Kansas, Kansas, 1960.
The proceedings from the conferences are extremely informative. They present new methods and a vast array of technical information.

__________. Proceedings of the Second Conference, 1962.

__________. Proceedings of the Third Conference, 1964.

__________. Proceedings of the Fourth Conference, 1966.

Struppeck, Jules. The Creation of Sculpture. New York: Holt, 1952.

Vntracht, Opp:. Metal Techniques for the Craftsmen. Garden City, New York: Doubleday & Co., 1948.

(Continued)

(Continued) This book is an excellent guide for all metal technics.

Wood, Rawson. Investment Casting for Engineers. New York: Reinhold, 1952.